IUTAM, Symposium on multiscale modeling
and uncertainty quantification
of materials and structures

USING EXPERIMENTALLY DETERMINED RESONANT BEHAVIOUR TO ESTIMATE THE DESIGN PARAMETER VARIABILITY OF THERMOPLASTIC HONEYCOMB SANDWICH STRUCTURES

Stijn Debruyne, Dirk Vandepitte, Korneel Van Massenhove

Department of Mechanical Engineering
Katholieke Universiteit Leuven (KUL)
Celestijnenlaan 300b, 3001 Heverlee, Belgium
e-mail: stijn.debruyne@khbo.be, dirk.vandepitte@mech.kuleuven.be,
korneel.vanmassenhove@khbo.be

Key words: Thermoplastic honeycomb panels, homogenized model, stochastic model updating, design parameter variability, correlation length

Summary. *This paper discusses how design parameter variability of thermoplastic honeycomb sandwich structures can be estimated using their experimentally determined modal behaviour. The cases of beams and rectangular panels under free boundary conditions are treated.*

ABSTRACT

Honeycomb panels are sandwich structures. They combine a high specific strength and stiffness with a low areal mass. Consequently, these structures are ideally suited for ground transportation vehicle purposes. They have a complex but regular geometry.

This paper describes the full process of estimating the variability of some of the design parameters of thermoplastic honeycomb structures. Figure 1 illustrates the specific type of MonoPan® structures used in this research. The uncertainty of the various design parameters is estimated from the experimentally determined modal behaviour of a set of honeycomb beam and panel samples. This work thus deals with uncertainty quantification by considering an inverse problem. Variability analysis are carried out at different scales in order to obtain a full image of the impact and origin (from the manufacturing process) of honeycomb design parameter variability.

Figure 1: typical MonoPan® thermoplastic honeycomb structure

A first part of the paper discusses the specific type of glass fibre weave reinforced thermoplastic honeycomb structures used in this study as test samples. A first set of test samples consists of 22 honeycomb sandwich beams, all with a length of 850 mm, a width of 50 mm and a thickness of 25 mm. Seven virtually identical panels (length: 2500 mm, width: 1200 mm and thickness: 25 mm) are the second set of test specimens used in this study. It is discussed which design parameters govern the dynamic behaviour of these freely suspended structures. A number of design parameters can be determined experimentally. The observed variability is analyzed in terms of its amount of scatter and its scale. Some parameters cannot be measured easily so they have to be determined indirectly.

Further, this article discusses the full process of experimental modal analysis. It is discussed how the measurements are set up and how the modal parameters of interest are estimated for each of the test beams (see figure 2) and panels.

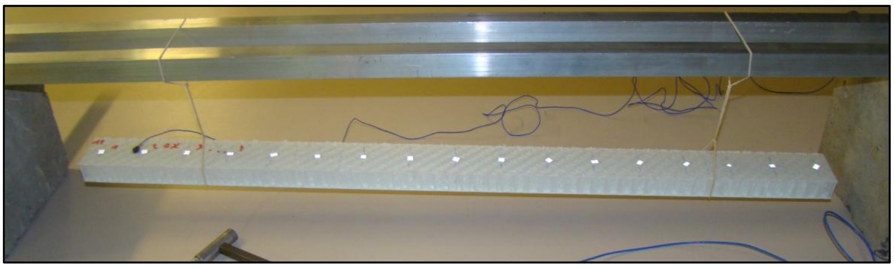

Figure 2: set-up for experimental modal analysis on honeycomb sandwich beams

Experimental modal analysis is a process that is subjected to many error sources which lead to some variability on the obtained modal parameters (resonance frequencies, mode shapes and damping factors). Since this research work deals with uncertainty quantification, focus is laid on the estimation of the modal parameter variability. Both measurement errors and modal parameter estimation errors are discussed and estimated.

Next, the paper explaines how a suitable FE-model is constructed to calculate resonance frequencies and mode shapes of honeycomb beams and panels with free boundary conditions.
It is outlined how the (elastic) parameters of the homogenized FE-model (using orthotropic material properties for both skin faces and honeycomb core) are obtained from the real physical parameters of skin faces and honeycomb core through a mix of experiments and numerical simulations. The panel model is devided into a number of intervals, each interval having constant values for the mass and elastic material properties. In this case, 240 intervals are considered in the panel model and 17 in the beam model. For the panel models, six elastic material properties are the parameters of interest. These are the Young's moduli of both skin faces in lenght and width direction and the two relevant out-of-plane shear moduli of the homogenized honeycomb core. In case of the honeycomb beams, only the in-length Young's modulus of the skin and the out-of-plane core shear modulus are the two considered elastic parameters. With respect to the considered sets of elastic parameters, the FE-models of the different test panels are updated using resonance frequencies and mode shapes, obtained through

experimental modal analysis. Figure 3 shows an example of a numerical/experimental mode shape pair for the panel case.

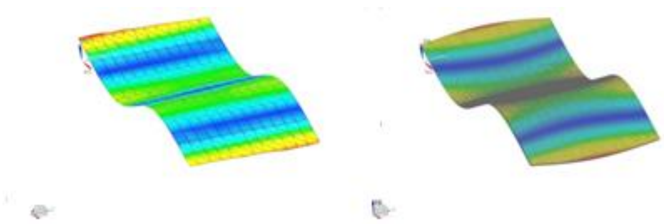

Figure 3: experimental (left) – numerical (right) mode shape pair (panel with size: 2500x1200x25 mm)

In case of the panels, the number of FE-model parameters to be updated, is much greater than the number of available update targets (resonance frequencies and mode shapes). This leads to an underdetermined model updating problem. It is discussed how stochastic model updating is applied to deal with this specific problem. Through this stochastic model updating process, databases are obtained for each of the considered elastic parameters and for all test structures.

Furthermore the article describes how the dynamic behaviour of a honeycomb panel can be regarded as a stochastic process that is governed by a set of stochastic variables, each having some variability. Considering the inverse problem and taking into account the whole set of test samples, each of the considered elastic model parameters is treated as a stochastic random field. Two types of uncertainty are discussed and estimated. The epistemic uncertainty is the uncertainty that arises from the fact that only limited experimental data (seven panels) is available for the estimation of probability density functions of the considered elastic parameters. The aleatory uncertainty is the uncertainty that is related to the inherent physical variabilty of the elastic parameters. It is also outlined how the implementation of the random field method is validated by means of a number of tests.

An important factor to relate the variability of a model parameter with its underlying physical variable quantities is the correlation length. From the covariance matrices, estimated by implementing the random field method, suitable correlation functions are obtained. The correlation length describes at what scale the considered parameter of interest is varying. In the paper it is outlined how the correlation length is estimated for the different elastic parameters. Hereby it is considered that the manufacturing process of the honeycomb structures may induce periodical variability of some elastic parameters.

Finally, the variability of the elastic model parameters is related to the variability of the underlying geometrical parameters of both skin faces and honeycomb core. The estimated correlation lengths are a tool for this purpose.